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ADP010791

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The Dangerous Virtual Building, an Example of the Use of Virtual Reality for Training in Safety Procedures

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Abstract
There is an ancient proverb that says *"Tell me and I will forget. Show me and I may remember. Involve me, and I will learn"*. This has been the main principle behind the big raising of immersive technologies in the field of training and education.
Here we explain our experience in using this kind of technology in the area of work risk and incident prevention. The high accident rate suffered by the construction sector has been one of the reasons that have moved us to develop the system that this article describes. The objective of the system is the training of the operator in safety procedures on the job. For this reason a VR system has been created that on the one hand reproduces a similar environment to the one experienced by the operator in real life, and on the other hand it provides for a number of operations to be completed. These operations which are very usual for the worker in real life imply a risk that must be understood by the worker, e.g. walking around the construction trenches carrying some type of load could cause a loosening of the ground resulting in death. For the complete training of the worker, the virtual environment contains the three fundamental phases of the construction of a building. Besides all of the general tools of the job may or may not have a safety component. So the number of dangerous operations that the system provides for and monitors are encountered in real life (working on a scaffolding, in trenches, on roofs, on the various floors, crashes, falls, overloads, etc.) By means of training and learning about the risks involved in the operations (from the most simple) you will obtain the best preparation in the sector, reducing therefore the rate mentioned above.
Using the system the worker is really involved in the task, and is able to understand the real risk that the task carries out, because he is in front of a screen that shows the object in its actual size and he has to make the proper decision. The system do not intent to train him or her in the skills of the task but in the safety way to proceed in its development.
This is a case that can be port to other military or civil areas where not only are important the skills but also is necessary to observe a methodology that ensures a safety performance.
We point out also in this paper how is possible using low-cost equipment to produce a good degree of immersive system. This is an important point in order to extend the use of those systems to such a sector or when the number of subjects to be involved in the training process make necessary to use a elevate number of simulation systems.

Introduction and capabilities of the system
Virtual environments are of major interest to computer graphics researchers; this is due, in part, to their ability to immerse the user in a computer-generated alternate reality in which we can easily recreate scenarios which are too dangerous, difficult or expensive to play in real life (Bukowski, 1997).

In this paper, we present an approach to this kind of system, the dangerous virtual building system (DVB) is an application of visual simulation, oriented to worker's education in the field of civil construction (Alkoc, 1993). One of the main goals to achieve by the system is the training of the operator in safety procedures on the job, and the second is to give us a measurement or an evaluation of these safety tasks.
The DVB has been designed to simulate a finite number of risky procedures that could occur in a real work environment. Demonstrating these procedures and evaluating the risks that each one implies, the workers can learn or review the safety routines that are often forbidden. Later the application will provide a measurement of the learning of capabilities of each worker in these safety procedures.

The main user in the DVB system, will be a student of a course in safety tasks, who works in construction field. Generally, the student doesn't know how to use most of the common tools utilised in computers such as a mouse or a keyboard. So in order not to hinder the learning process an instructor is needed to advise in the management of the system and to explain the goals to be achieved during the simulation.

A prototype of this system, based on SGI workstation, was developed and tested (Lozano, 1999) and currently we are developing a new open architecture focussed on the DVB training system.

The system under development consists of a centralised instructor control sever plus twelve simulation nodes (based on PC architecture). Each one of the subjects is immerse in his/her own simulation process and the

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Paper presented at the RTO HFM Workshop on "What Is Essential for Virtual Reality Systems to Meet Military Human Performance Goals?", held in The Hague, The Netherlands, 13-15 April 2000, and published in RTO MP-058.

instructor can control the development of each exercise. The system has been based on distributed standard architecture (CORBA) and for the output of the simulation three possibilities has been offer: Head Mounted Display, flat monitor or 2×2 meters screen. The core of simulation graphics has been developed using low-cost graphics platforms with LINUX operative system and Performer libraries. The whole system offers enough graphic quality for both purposes, the training phase and the instructor node.

This instructor, who knows the capabilities of the system, will control the simulation, ordering some kinds of tasks for each student and enabling or disabling the proper conditions for that task. Later he will check the results given by the DVB in the learning process and will be able give us the level achieved for each student.

The way to show these procedures has been based on a VR application, so that, we can reproduce the familiar environment of the worker and he must interact with the system in order to achieve his goals. The input device used for the subject interact with the system has been and standard joystick.

The main capabilities of the system are:

- Simulate a virtual building environment managed from a subjective point of view (the camera) and controlled from the Joystick position (Cabral, 1996).
- Simulate and control the worker-environment interaction: The system simulates a number of risk situations (defined below), and must control the reactions and consequences.
- A number of elements (objects, tools, ... etc.) must be created and the interaction must be controlled by one specific module called the *worker's bag* (Santonja, 1996).
- The system takes into account the legislation regarding safety rules, and informs the worker if his behaviour doesn't comply with these rules.

In the rest of this article we will define each one of these capabilities, exploring in this way the contents of the system.

The Object Interface

The interaction with the objects commonly used in the building area is a very important element of the application. The application must allow the worker to be able to select objects and carry out an action with them. For this purpose, an object interface has been designed similar to the interfaces of adventure games. Whenever we wish we could show at the bottom of the screen an area composed of the next elements:

- The upper row is used to show the objects that the worker wears at a given moment, such as a helmet, gloves, etc.
- The middle row shows the objects that the worker carries in his hand, his pockets, or work belt, such a large hoe, a shovel, etc.
- The right area shows the objects that the worker carries in the wheelbarrow, if the worker finds it necessary to collect them. The wheelbarrow will then appear in the middle row as a transported object.
- The lower row shows the different actions that can be carried out with the currently selected object (Figure 1).

Figure 1: The Object Interface

Pressing the right spaceball button shows the object interface area. Once opened the object interface, can be in one of two possible states:

- Object selection: it allows the free choice between the objects that the worker wears, transport, or carries in the wheelbarrow.
- Action selection: it allows free choice between the possible actions for the currently selected object.

Once an object and the action the worker wants to perform on that object has been chosen, it will be checked to see if such an action is feasible with that object, and if it may carried out. The selection process can be summarised in Figure 2.

The verification of the action with the selected object is one of the most important steps in the diagram shown above. In order to carry out this verification, it is necessary is to take into account the weight and maximum volume the worker can support. Moreover, there is also a necessity to verify the number of 'spots' that remain free for an object to be carried. These 'spots' are the pockets, the belt, the worker hands, etc.

In order to help to the verification of the actions, a mask is assigned to each object with the possible action that can be performed with that object. As actions are performed over the objects, the mask will be modified to update the future possible actions over the object. In this manner the execution of an action over an object can be completely controlled.

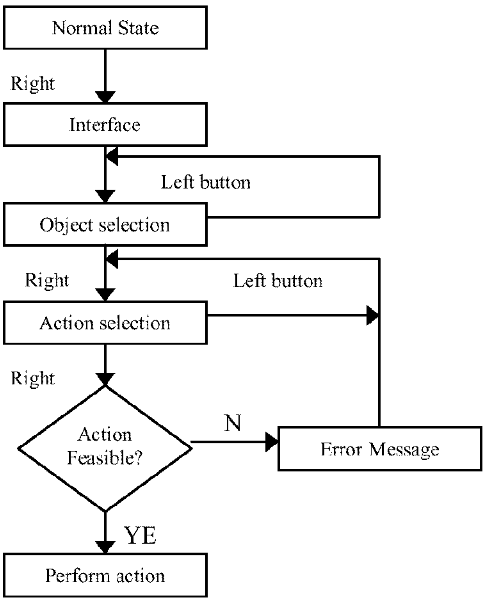

Figure 2: Object interface state diagram

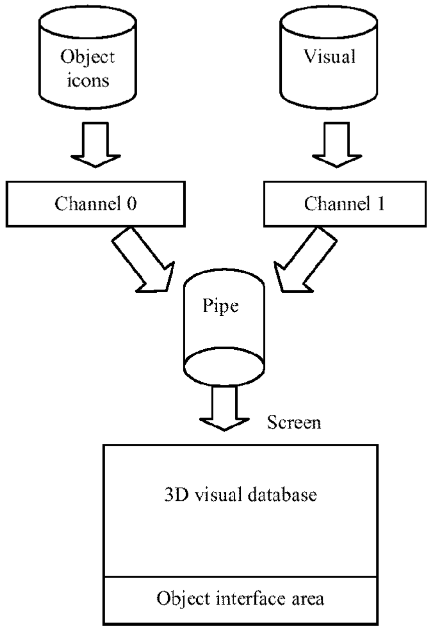

Figure 3: Channel Structure

In Figure 3 we can see an image of the application object interface with some of the building area objects loaded.

This figure shows us the objects that the worker wears in the first row of the object interface: the worker wears work suit, work boots, a tool belt, a safety harness, a helmet, and work gloves. In the row showing the transported objects, the worker carries an anti-gas mask and the wheelbarrow with the objects shown to the right of the interface (a large hoe, a shovel, a brick and a cement sack). The current selected object is marked with a blue square, as we can see in the helmet icon. The four actions possible over the selected object are shown in the lower row: cancel, transport, leave, and put into the wheelbarrow.

The interface object area is a dedicated channel different to the visual database scene channel, with its own visual database which is composed of small plane (two dimensional) objects with its texture applied (Rohlf, 1994). This structure is shown in Figure 3.

Danger situations

The main purpose of the application is training of the construction workers in issues concerning safety conditions (Lozano, 1998; Bukowski, 1997). This embraces knowing the essential equipment for each kind of task, and the right way of doing that task.

The stage has been divided in five areas and two access points, one for the workers and the other for the vehicles. The areas are arranged as shown in Figure 4.

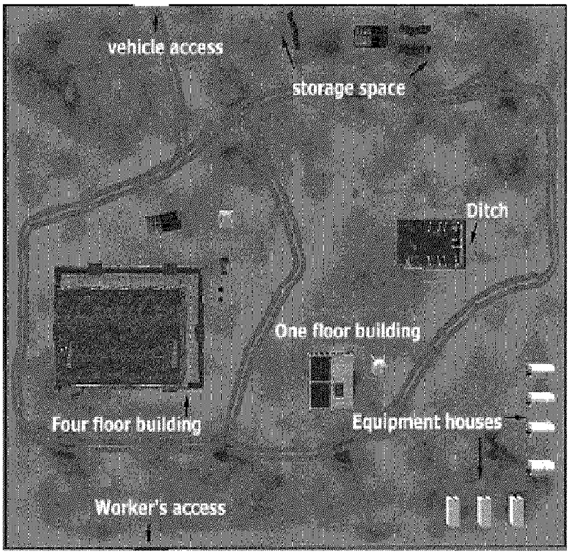

Figure 4: Arrangement of working areas

The five working areas are as follows:

- Equipment barracks: There are seven barracks with different equipment and clothes that the workers can use. There are elements, which are suitable for general working in the building area, such as boots and gloves. However, there is more than one element for each type of clothes. For example, there are rain and anti-slide boots, and the worker must choose the right equipment for the task he is going to do according to the weather conditions.

- Storage space: This is an area where the building elements are stored. The workers should leave things like cement sacks, wheelbarrows, and general working tools in this area.
- The ditch: There is a ditch with two propped up walls and the other two unpropped. The worker can go down to the ditch trough a ladder.
- One floor building: It is a small area with a building that has one floor and is under construction. There is a scaffold for the worker to use when working on the facade and a ladder to go up to the first floor.
- Four floor building: It is the biggest building in the building area, and is also under construction.

In addition, there are a couple of access points. The workers must use the people access point; otherwise they could suffer serious injury.

In the next images we can see situations corresponding to the areas mentioned above:

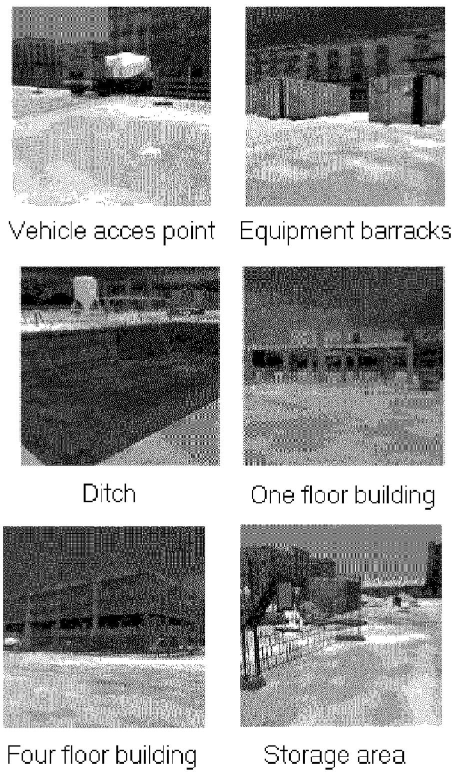

Figure 5: Working areas of the application

Training can be broadly defined as the learning or acquisition of skills in order to enhance performance at a given task or job (Burinston, 1995). In order to train, the building workers have thirty-six different dangerous situations that have been defined throughout the building areas. There are several types of situations:

- Situations that do not depend on the area which the worker is working in: this situations depends on time, altitude, weight, etc. Examples of these situations are:
  - Jumping: if the worker jumps from a surface (a scaffold), he could get injured if the altitude is moderate (up to four meters) or even die if he jumps from a higher site.
  - If the worker accumulate too many objects or materials in concrete areas, there is a risk of terrain collapse in those areas. So the worker must wear the necessary safety equipment in case such a situation occurs.
  - Collision with dangerous objects: if the worker drops a dangerous object (such a large hoe), it could cause injury to other workers. This will be advised by a warning message.
- Situations that depend on the place or area which the worker is working in: there are a lot of these situations, so we will describe a few organised by area:
  - Vehicle access area: if the worker goes into the building area through the vehicle entrance, he could be run over by a truck (Bayarri, 1996).
  - Storage space: here, the worker must walk carefully because there are dangerous objects in the area, so he should not stay on this area for a long time.
  - Ditch: in this area, there is a risk of terrain collapse if the worker walks in the zone that is not yet secure. If the worker wears a safety belt, he could be rescued in case of terrain collapse.
  - One floor building: here there is a scaffold that does not comply with to building regulations, so there is a risk of falling. The worker must be attached to the scaffold through the safety belt in order to prevent an accident.
  - Four floor building: in this area there are several different situations.

There is a trench surrounding the building with duckboards for the workers to go into. If the worker jumps the trench, he could fall and be seriously injured. So he must use the duckboards to access the building.

Walking under the building without a helmet is dangerous, because some object dropped from a higher floor may hit the worker.
There are gaps for the lifts that are surrounded by wooden fences, but in some cases the fence is not complete. In this case, the worker must pick up a wood board and complete the fence to prevent a possible accident (such as falling through the gap in the fence).
There are provisional ramps for the workers to go up to higher floors. Some of these ramps lack bricks, so the worker may slide and fall. In this case, the worker must use the correct ramps, or wear suitable boots.

The following images show some of the above situations:

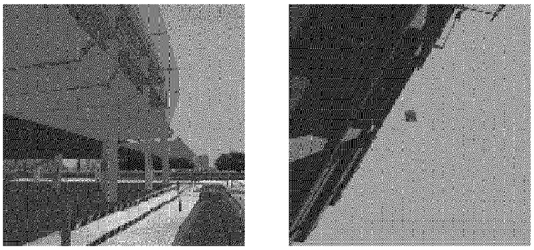

Figure 6: Risk of sudden fall of a brick from the roof

In the left-hand picture the worker is walking under a protective cover, so there is not a risk of the object falling. In the right hand picture, a brick is falling on to the worker. As there is no protective cover, the brick will hit the worker, and if he is not wearing a helmet he will be badly injured.

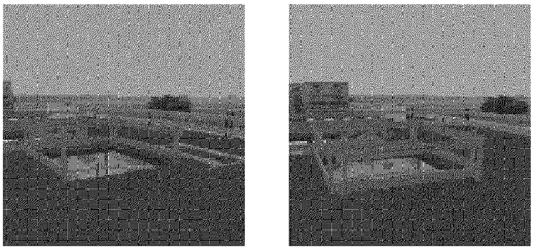

Figure 7: Risk of falling down through the lift gap

The left-hand picture shows that the fence surrounding the lift gap lacks an element. The worker must secure the gap zone by placing the wooden board on the floor.

In summary, the first action that the worker should undertake is to go to the equipment barracks and put on the correct clothes, depending on the area that he is going to work in. Then he will be prepared to begin his task, and go to the corresponding area. When finished, he must leave the elements, which he has worked on, in the storage area, and the clothes in the equipment barracks. In order to leave the building area; the worker must use the people access. The simulation restarts whenever the worker is killed by an accident, and the worker must go again to the barracks. In this manner the worker will learn the correct elements he must use in the corresponding areas.

Evaluation and future works

The previous prototype version of this system, which was running on a Silicon Graphics workstation, was tested with more than forty workers.

We can summarise the main objectives of those tests in two aspects: firstly, evaluate the degree of acceptance of the system in a group of people that is not familiar with this technology, and secondly evaluate transference of learning when it was produced.

Concerning to the first aspect pointed out previously, the basic analysis of the queries performed to the workers concluded that they were very excited with the use of this technology. At the first step users saw the system as a new experience and they were more active than in other teaching media, like video.
However at this point some problems were detected concerning to the navigation in the three dimensional environment and its location aspects. A couple of motion sickness cases were detected.
Focussing on the second point, a good learning transference was detected taking into account the written test performed after the exercises.

Nevertheless is important to notice that these tests were only initial evaluations that they only try to evaluate the convenience of starting the process of implementing actually a profitable system.

One of the problems detected in the first prototype was the high cost of the system. The current system has almost the same capabilities and a cost twenty times lower.

We have been also working in solving the problems of navigation, basically making the use of the joystick more intuitive and limiting in some ways the freedom of movements that some times produced a problem of location.

The current system as we have explained before is being developed with twelve simultaneous training nodes. The idea is to make this system portable in order to be installed into a forty-feed truck where the training process will be developed directly at the building area. By this way we will reduce the learning cost and will increase the productivity, taking into account the number of persons able to run the system.

The process of real evaluation of the system will start by the end of the year when the whole system will be ready to go to the real building areas.

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